frontiers | Frontiers in Environmental Science

TYPE Specialty Grand Challenge
PUBLISHED 20 September 2022
DOI 10.3389/fenvs.2022.1019628

OPEN ACCESS

EDITED AND REVIEWED BY
Martin Siegert,
Imperial College London,
United Kingdom

*CORRESPONDENCE
Steffen Fritz,
fritz@iiasa.ac.at

SPECIALTY SECTION
This article was submitted to Environmental Citizen Science, a section of the journal Frontiers in Environmental Science

RECEIVED 15 August 2022
ACCEPTED 02 September 2022
PUBLISHED 20 September 2022

CITATION
Fritz S, See L and Grey F (2022), The grand challenges facing environmental citizen science.
Front. Environ. Sci. 10:1019628.
doi: 10.3389/fenvs.2022.1019628

The grand challenges facing environmental citizen science

Steffen Fritz[1]*, Linda See[1] and François Grey[2]

[1]Advancing Systems Analysis Program, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, [2]Citizen Cyberlab, SDG Solution Space, University of Geneva, Geneva, Switzerland

KEYWORDS

grand challenges of citizen science, quality, complementing authoritative data, citizen engagement, data sharing, digital divide, social transformation

Introduction

Citizen science is becoming increasingly popular as a way of engaging citizens in environmental monitoring. There has been a wide discussion around what citizen science is and is not. For example, should it include only active or deliberate contributions by participants, or can it also include passive or involuntary citizen participation, e.g., where crowdsourced data on social media are analyzed for a specific scientific purpose? Should it only be voluntary, or can it also include payments? While the debate is important (Haklay et al., 2021), here, we use the term citizen science in the broadest sense possible, to mean the engagement and participation of non-professional scientists in the production of scientific knowledge. Although citizen science has traditionally been used in an environmental monitoring context, an important and very valuable characteristic is that it has the potential to reach beyond individual scientific disciplines and to attract wider public participation (Bonney et al., 2009). This is particularly true in the digital age where technology has been a key enabler of citizen participation in a much wider range of research, including technologically demanding fields such as particle physics or synthetic biology, as well as whole disciplines such as medicine, the social sciences and the humanities (Pykett et al., 2020; Tauginienė et al., 2020; Haklay et al., 2021). Hence, for this special collection of environmental citizen science that was launched in March 2022, we want to include any research using citizen science methodologies that is relevant to environmental science, in a broad and inclusive manner.

The use of citizen science for environmental research is evolving rapidly, partly due to the increasingly visible impacts of climate change, which is galvanizing public participation globally. In this paper we discuss six grand challenges that face this growing area of research, namely: 1) Perennial issues that the scientific establishment raises about data quality in citizen science, as applied to environmental research; 2) the use of citizen science by governments, local authorities and National Statistical Offices (NSOs) as a source of non-traditional data for monitoring and decision making; 3) new forms of engagement, motivation and retention of citizens; 4) open data and the sharing of citizen science data; 5) the integration of data from new digital technologies and how citizen science can help bridge the digital divide and inequalities in participation; and 6) how environmental citizen science relates to research on the global environmental challenges that humanity is currently facing such as the climate emergency, the continued destruction of the rainforests, dramatic losses in biodiversity, and increasing inequality, to name just a few. On this last point, in a recent youth survey by

UNESCO, climate change and the loss of biodiversity were considered to be the most important pressing challenges for the next decade (UNESCO, 2021). Hence, environmental citizen science, with its openness to participation by youth, and indeed people of all ages and backgrounds, has a particularly strong potential to address global environmental challenges and be a catalyst for transformative societal change. In the following sections the identified grand challenges are discussed in more detail.

Challenge 1: Data quality

Data from citizen science has made significant and sometimes crucial contributions to scientific research in a wide range of different research fields. Citizen science is widely accepted by academic institutions around the globe, and many dedicated citizen science associations and centres have been created by mainstream academic organizations. There remain sceptics who question the reliability of citizen-generated data. And of course, any scientific result needs to be held to the highest standards of reproducibility appropriate to the field of research in question: citizen science is no exception. Nevertheless, the much wider acceptance of citizen science in mainstream science is evidenced by dedicated funding programs in support of it, such as the European Commission's Science with and For Society (SwafS) program. In particular, citizen science is also increasingly being recognized as a potential source of information for official statistical reporting and authoritative environmental monitoring such as the United Nations Sustainable Development Goals (Flückiger and Seth, 2016; Fritz et al., 2019; Fraisl et al., 2020). As use of non-traditional data sources by government bodies grows, so will the demand for a more refined distinction between the conditions that determine whether citizen-generated data are of sufficient quality for a certain purpose, and where novel types of data filtering and curation may be needed. There are many ways to increase the accuracy of citizen science data, for example, through the use of multiple observations at the same location, the use of plausibility measures, and independent automatic quality checks as well as comparison of data from citizens with data collected by experts (See et al., 2013; Salk et al., 2022). One innovative way of improving the quality of data provided by citizens is through the use of near-real-time feedback. For example, in one citizen science project called Fotoquest Go, it was shown that by providing near-real-time feedback to citizens during the data collection campaign, the overall agreement between the crowd and the experts increased from 69 to 90% for a land cover classification using a simple 10 class legend, and from 37 to 82% for a more detailed legend (Laso Bayas et al., 2020). A further rapidly evolving field of research is the combined use of citizen science and artificial intelligence (AI) where, for example, a machine learning (ML) algorithm can be used to filter large data sets from social media before further and more subtle refining is done by human intervention. An example of this is the combined use of AI and crowdsourcing to identify venomous snakes (Durso et al., 2021).

Increasingly, scientifically important data sets are being collected in a passive way by sensors that are used or owned by citizens. In these examples, the quality of the observations depends partly on the proper use of the sensor but much more on the quality of the actual sensing device. Whereas some devices and sensors used by citizens have had problems in the past and have led to inaccurate information, for example, on air quality (Ekman and Weilenmann, 2021), the reliability of these types of low-cost air quality sensors is increasing rapidly (Watne et al., 2021). In general, the cost of sensors as well as wearables has decreased dramatically, and many types of sensors (e.g., air quality sensors, temperature sensors, water quality sensors, etc.) are now affordable for citizens.

Challenge 2: Potential use of citizen science environmental data by governments, local authorities and NSOs

Countries increasingly realize that citizen science can potentially play an important role towards addressing national as well as global challenges, in particular, for achieving the United Nations Sustainable Development Goals (SDGs), which involve a large number of specific targets and indicators, many of which NSOs are poorly equipped to monitor. Several legal and policy frameworks have already been implemented that pave the way for using data from citizen science. These include the 2015 United States White House Memorandum on Citizen Science (Holdren, 2015); the United States Crowdsourcing and Citizen Science Act (US Congress, 2016); the European Open Science Policy Agenda (European Commission, 2019a); the recommendations of the European Open Science Policy Platform (OSPP, 2020); action 8 of the EU roadmap to streamline environmental reporting (European Commission, 2017); and the Ministerial Declaration at the UN Environment Assembly (UNEP, 2019). Very recently, citizen science data have been used in the EU strategy on plastics and in the recent Single-Use Plastics (SUPs) Directive by, for example, identifying the 10 types of litter that are most commonly found on beaches (European Commission, 2019b).

A number of papers have shown that citizen science has untapped potential for monitoring progress towards the SDGs (Fritz et al., 2019; Fraisl et al., 2020). The latter paper demonstrated that citizen science is already contributing to the monitoring of five SDG indicators and that citizen science has the potential to contribute to another 76 indicators. Bearing in mind that individual countries have many environmental targets and indicators that go beyond those specified by the UN for the SDGs, and that they deal with specific national or

regional issues, it is clear that citizen science can contribute to the monitoring of a wide-range of environmental issues where NSOs need data, including around one-third of all SDG indicators.

Analysis shows that the greatest inputs from citizen science to the SDG framework relate to SDG 15 Life on Land, SDG 11 Sustainable Cities and Communities, SDG 3 Good Health and Wellbeing, and SDG 6 Clean Water and Sanitation (Fraisl et al., 2020). However, it has also been highlighted that such monitoring of the SDGs, or sustainability more generally, is not always that straightforward, and that many current citizen science projects are not adapted for this purpose. In particular, the challenge of balancing local needs with national reporting requirements, without overburdening small low budget citizen science projects with the strict requirements of SDG reporting (Moczek et al., 2021), is a significant challenge (Pateman et al., 2021). While a number of citizen science projects could directly contribute to the monitoring of the SDGs with some additional efforts in order to standardize their data for SDG reporting needs (Fraisl et al., 2020; Moczek et al., 2021), the design and setting up of interfaces to UN or NSO databases would highly facilitate this process (Moczek et al., 2021).

While recent studies attempt to identify where citizen science could be most useful for SDG monitoring, there are fields such as agriculture where citizen science is currently playing only a very minor role, but opportunities abound. An analysis by Scistarter (scistarter.com), the largest citizen science platform, has shown that only 1% of all projects have an agricultural focus (Ryan et al., 2018) In their analysis, the authors showed that there is tremendous potential in the agricultural sector for citizen science. For example, citizen science could contribute much more than is currently done to monitoring pests/pathogens and invasive species, and in preserving biodiversity and ecosystem services by raising awareness about pollinator diversity and occurrence as well as its importance. Furthermore, there is an untapped potential in the field of enhancing food safety, nutrition and flavour, in particular, with respect to the role of microbes as well as in the field of social justice and animal welfare in agriculture.

Challenge 3: Engagement, motivation and retention of citizens

Another important challenge in citizen science is how to incentive citizens to participate in science and to answer the question: What is in it for me? Here, clear communication regarding how the data are being used and why the data are so critical play an important role. For example, a number of incentives have been tried to increase engagement and retention, such as prizes and co-authorship (See et al., 2022) and information nudges, e.g., through the Earth Challenge (EARTHDAY.ORG, 2022), although citizens are also interested in helping science and the intellectual challenge (Curtis, 2015).

A strong incentive in the context of the climate crisis is the possibility, through the use of citizen science data to guide national and international policy, for participants to feel that their efforts are worthwhile, and that citizen-generated data have a clear role to play in the transformative process that tackling climate change requires. It has been stressed that citizen science projects should try to tap into a larger audience that better represents society at large. However, citizen science projects do not always collect demographic information to understand who is actually participating (Mervis, 2018).

Furthermore, there is a need for greater openness by scientists to engage with the wider public and to communicate science in a clearer and simpler way by, for example, avoiding jargon and in ways that are clearer and more understandable to non-specialists. Scientists need to break out of their ivory towers and engage more widely with society and citizens.

Challenge 4: Data sharing and open data

Many citizens are making their personal data available on various internet platforms these days, with little or no concern about the privacy implications. Many of the companies that exploit these data are under increased scrutiny in terms of their compliance with European GDPR (General Data Protection Regulation) and other regulations. The question is, how will scientists and organizations that may come to depend on similar citizen-generated data gain and maintain the trust of the citizens providing the data? To build trust it will need to be made clear from the start of a citizen science project that the data are not exploited by third parties for marketing and profit purposes, and that citizen science data used exclusively for research will need to follow strict ethical principles.

More research is needed on how, for example, passive data can be donated by citizens for scientific purposes. As one example, consider the many potential applications that a crowdsourced dynamic global GPS database might have had. If a selected representative group of people made their personal location data available *via* a very simple app during the peak of the Covid-19 pandemic, we might have known earlier and with higher confidence to what degree the first wave of the pandemic changed human mobility and, therefore, carbon emissions from traffic. A near real-time global transport monitoring database might, for example, help in understanding very quickly the effects of green policies on reducing car traffic and car mobility. Some organizations, such as Google, have made such data available. But often it is in a non-machine-readable form (e.g., as PDFs—see https://www.google.com/covid19/mobility/), which requires unnecessary and substantial effort to exploit for scientific and global analysis.

We acknowledge that it may not be in the commercial interest of private companies to make the data they gather from citizens free and open. Indeed, it could generate legal risks for such companies, too. But such data, used ethically for legitimate scientific purposes, could greatly benefit society. Engaging with these companies at the level of national or UN policies can help to open up some of these commercially-generated citizen data sets for science. But more bottom-up citizen data collection activities are clearly needed, and citizen data needs to be openly shared following the FAIR principle (Wilkinson et al., 2016). Ultimately, bottom-up data collection could have an advantage over commercially acquired data. For example, in the field of remote sensing, reference data used to train classification algorithms are not being openly shared by companies although there are now examples of reference data collected by citizens that have been made free and open (Laso Bayas et al., 2017; Lesiv et al., 2022).

Challenge 5: Digital opportunities and the digital divide

One of the future challenges for citizen science is the integration of passive sensor data directly from smartphones or wearables as well as human perception data into official data streams while at the same time fully respecting privacy and compliance with the EU's GDPR. Data donation for science is becoming a new trend, with projects like Open Humans, allowing scientists, companies, NGOs and policy makers access to unprecedented sources and quantities of new data. Standard smartphones or wearables now provide, for example: location, movement, individual carbon mobility footprints, health related data, and much more.

A citizen social science approach has also been recently proposed (Pykett et al., 2020) to research human emotions in cities, linking it to wearables. By establishing the link to well-being, this can lead to a better understanding of urban stress. The use of wearables and other low-cost sensors represent an untapped potential for improving our knowledge of factors that can help to improve human well-being, access to green space, improving city planning as well as implementing measures to reduce the carbon emissions of cities.

Mostly, citizen science has been an activity of the Global North, and confined to relatively rich countries, where people have the time for volunteer activities and unpaid hobbies. Yet the Global South has leapfrogged some important stages of development thanks to digital technologies, with cell phone penetration in many regions high where there are still no landlines. In emerging economies, citizen science activities are much less popular, as an inspection of data on many open citizen science platforms, such as iNaturalist, clearly show.

One way to increase the contribution of data from citizens could be through micropayments. Microfinancing represents another opportunity for emerging markets to leapfrog traditional banking technologies and switch to phone-based rewards. Such an approach could also help to provide new opportunities to poorer communities and people working in the informal economy, which is the case in the majority of young people in most African countries, for example. A case in point is the Youth Agency Market developed by UNICEF. This digital platform connects job seekers to job providers and was setup to provide new livelihood opportunities to African youth, including collection of citizen science data (Ghedin, 2021).

Challenge 6: The contribution of citizen science to global transformational change

It is increasingly clear that in order to address the big global challenges that societies are currently facing, greater engagement of citizens is required. For citizens to act, in particular, through positive behavioral change to reduce their climate and environmental footprints, they need to measure what their current impact is. Governments need to know more about the impact of their citizens, too, in order to shape policies that effectively address global challenges that require collective action.

One important theme that has been repeatedly discussed in IPCC reports is the critical role that citizens play in helping to achieve the carbon emissions reduction required by the Paris Agreement, by changing their behavior (IPCC, 2018; Williamson et al., 2018; Gosnell and Bazilian, 2021). Science-driven climate policies are also needed to provide the necessary boundary conditions for an accelerated transformation of society to lower, and in due course, zero net, carbon emissions. It has been further demonstrated that citizen science can be a critical ingredient in triggering behavioral change (Jordan et al., 2011; Jones et al., 2013; Morrow, 2013; Van Brussel and Huyse, 2018), although much more research is needed in this area.

Another important contribution citizens can make in the field of climate and environmental action is their role in shaping and formulating climate and environmental policies. Whereas citizen science is often viewed by professional scientists as a cheap source of data, which can, in turn, be used for policy making, citizens can play a much more active role at a much earlier stage in the science to policy discourse, as the policy impact of the Fridays for Future movement, inspired by the actions of Greta Thunberg, clearly illustrate. Going beyond citizen protest, a recent paper by Kythreotis et al. (2019) argues that citizen engagement can encompass how local and indigenous knowledge can be integrated into science (truth) and policy (power) structures. A future can be envisaged where policy making can truly become a co-design process, giving citizens a clear and much more active role in the climate and environmental debate.

National and supranational organizations are showing increasing support for citizen science. For example, an EU report by Warin and Delaney (2020) outlines the various achievements that citizen science projects have made in the context of the Horizon 2020 funding scheme and advocates for further support for citizen science in the follow up funding program of Horizon Europe. Hence, the profile of citizen science has been raised at the European level.

In conclusion, we have outlined six challenges facing environmental citizen science, ranging from the methodological to the technological, and from the political to the ethical. The contributions to this special collection on Environmental Citizen Science address all of these challenges, in one way or another, and provide intriguing visions of how environmental citizen science may evolve in the coming years. At the crossroads between new opportunities and risks for citizen science, and with the urgency of global environmental change wrought by the climate crisis, the timing of this special collection could not be more opportune. We hope that it will spur citizen scientists and professional academics alike to find new ways to collaborate and to respond to planetary emergencies.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., et al. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience* 59, 977–984. doi:10.1525/bio.2009.59.11.9

Congress, US (2016). Crowdsourcing and citizen science act of 2016. Available at: https://www.congress.gov/bill/114th-congress/house-bill/6414/text.

Curtis, V. (2015). Motivation to participate in an online citizen science game: A study of foldit. *Sci. Commun.* 37, 723–746. doi:10.1177/1075547015609322

EARTHDAY, ORG (2022). Global Earth challenge. Available at: https://www.earthday.org/campaign/global-earth-challenge/.

Ekman, K., and Weilenmann, A. (2021). Behind the scenes of planning for public participation: Planning for air-quality monitoring with low-cost sensors. *J. Environ. Plan. Manag.* 64, 865–882. doi:10.1080/09640568.2020.1787129

European Commission (2017). Actions to streamline environmental reporting. Available at: https://ec.europa.eu/environment/legal/reporting/pdf/action_plan_env_issues.pdf.

European Commission (2019a). Open science. Available at: https://ec.europa.eu/info/sites/default/files/research_and_innovation/knowledge_publications_tools_and_data/documents/ec_rtd_factsheet-open-science_2019.pdf.

European Commission (2019b). Single-use plastics. Available at: https://environment.ec.europa.eu/topics/plastics/single-use-plastics_en.

Flückiger, Y., and Seth, N. (2016). SDG indicators need crowdsourcing. *Nature* 531, 448. doi:10.1038/531448c

Fraisl, D., Campbell, J., See, L., Wehn, U., Wardlaw, J., Gold, M., et al. (2020). Mapping citizen science contributions to the UN sustainable development goals. *Sustain. Sci.* 15, 1735–1751. doi:10.1007/s11625-020-00833-7

Fritz, S., See, L., Carlson, T., Haklay, M., Muki)Oliver, J. L., et al. (2019). Citizen science and the united Nations sustainable development goals. *Nat. Sustain.* 2, 922–930. doi:10.1038/s41893-019-0390-3

Ghedin, N. (2021). *The Digital Marketplace Yoma: Empowering African youth on their journey from learning to earning.* Available at: https://ec.europa.eu/international-partnerships/projects/digital-marketplace-yoma-empowering-african-youth-their-journey-learning-earning_en. International Partnerships - European Commission. https://ec.europa.eu/international-partnerships/projects/digital-marketplace-yoma-empowering-african-youth-their-journey-learning-earning_en [Accessed May 28, 2022].

Gosnell, G. K., and Bazilian, M. D. (2021). Changing behaviour is the key to solving the climate challenge. *Nat. Hum. Behav.* 5, 294. doi:10.1038/s41562-020-01047-8

Haklay, M., Fraisl, D., Greshake Tzovaras, B., Hecker, S., Gold, M., Hager, G., et al. (2021). Contours of citizen science: A vignette study. *R. Soc. Open Sci.* 8, 202108. doi:10.1098/rsos.202108

Holdren, J. P. (2015). Memorandum to the heads of executive departments and agencies on addressing societal and scientific challenges through citizen science and crowdsourcing. Available at: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/holdren_citizen_science_memo_092915_0.pdf.

IPCC (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Jones, M., Riddell, K., and Morrow, A. (2013). The impact of Citizen Science activities on participant behaviour and attitude. Project report. Available at: https://www.environment.gov.scot/media/1432/phase-2-report-the-impacts-of-citizen-science-activities-on-behaviours-and-attitudes.pdf.

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., and Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs: Citizen-scientist knowledge gain. *Conserv. Biol.* 25, 1148–1154. doi:10.1111/j.1523-1739.2011.01745.x

Kythreotis, A. P., Mantyka-Pringle, C., Mercer, T. G., Whitmarsh, L. E., Corner, A., Paavola, J., et al. (2019). Citizen social science for more integrative and effective climate action: A science-policy perspective. *Front. Environ. Sci.* 7, 10. doi:10.3389/fenvs.2019.00010

Laso Bayas, J. C., Lesiv, M., Waldner, F., Schucknecht, A., Duerauer, M., See, L., et al. (2017). A global reference database of crowdsourced cropland data collected using the Geo-Wiki platform. *Sci. Data* 4, 170136. doi:10.1038/sdata.2017.136

Laso Bayas, J. C., See, L., Bartl, H., Sturn, T., Karner, M., Fraisl, D., et al. (2020). Crowdsourcing LUCAS: Citizens generating reference land cover and land use data with a mobile app. *Land* 9, 446. doi:10.3390/land9110446

Lesiv, M., Schepaschenko, D., Buchhorn, M., See, L., Dürauer, M., Georgieva, I., et al. (2022). Global forest management data for 2015 at a 100 m resolution. *Sci. Data* 9, 199. doi:10.1038/s41597-022-01332-3

Mervis, J. (2018). Citizen science needs to look more like society, report says. *Science* 2018, aav9305. doi:10.1126/science.aav9305

Moczek, N., Voigt-Heucke, S. L., Mortega, K. G., Fabó Cartas, C., and Knobloch, J. (2021). A self-assessment of European citizen science projects on their contribution to the UN sustainable development goals (SDGs). *Sustainability* 13, 1774. doi:10.3390/su13041774

Morrow, A. (2013). The impact of Citizen Science activities on participant behaviour and attitude: Review of existing studies. Available at: https://www.tcv.org.uk/wp-content/uploads/2014/11/TheImpactofCitizenScienceactivitiesonparticipantbehaviourandattitude.pdf.

OSPP (2020). Open science policy platform: Final report. Available at: https://openscience.eu/open-science-policy-platform-final-report.

Pateman, R., Tuhkanen, H., and Cinderby, S. (2021). Citizen science and the sustainable development goals in low and middle income country cities. *Sustainability* 13, 9534. doi:10.3390/su13179534

Pykett, J., Chrisinger, B., Kyriakou, K., Osborne, T., Resch, B., Stathi, A., et al. (2020). Developing a Citizen Social Science approach to understand urban stress and promote wellbeing in urban communities. *Palgrave Commun.* 6, 85–11. doi:10.1057/s41599-020-0460-1

Ryan, S. F., Adamson, N. L., Aktipis, A., Andersen, L. K., Austin, R., Barnes, L., et al. (2018). The role of citizen science in addressing grand challenges in food and agriculture research. *Proc. R. Soc. B* 285, 20181977. doi:10.1098/rspb.2018.1977

Salk, C., Moltchanova, E., See, L., Sturn, T., McCallum, I., and Fritz, S. (2022). How many people need to classify the same image? A method for optimizing volunteer contributions in binary geographical classifications. *PLoS ONE* 17, e0267114. doi:10.1371/journal.pone.0267114

See, L., Bayas, J. C. L., Lesiv, M., Schepaschenko, D., Danylo, O., McCallum, I., et al. (2022). Lessons learned in developing reference data sets with the contribution of citizens: The geo-wiki experience. *Environ. Res. Lett.* 17, 065003. doi:10.1088/1748-9326/ac6ad7

See, L., Comber, A., Salk, C., Fritz, S., van der Velde, M., Perger, C., et al. (2013). Comparing the quality of crowdsourced data contributed by expert and non-experts. *PLoS ONE* 8, e69958. doi:10.1371/journal.pone.0069958

Tauginienė, L., Butkevičienė, E., Vohland, K., Heinisch, B., Daskolia, M., Suškevičs, M., et al. (2020). Citizen science in the social sciences and humanities: The power of interdisciplinarity. *Palgrave Commun.* 6, 89–11. doi:10.1057/s41599-020-0471-y

UNEP (2019). Draft Ministerial Declaration of the 2019 UN Environment Assembly "Innovative solutions for environmental challenges and sustainable consumption and production". Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/26151/Zero%20Draft%20Federation%20of%20Envir%20Ministerial%20Declaration%20%20of%20the%202019%20UN%20Environment%20Assembly.pdf?sequence=83.

UNESCO (2021). *The world in 2030: Public survey report*. Paris, France: UNESCO.

Van Brussel, S., and Huyse, H. (2018). Citizen science on speed? Realising the triple objective of scientific rigour, policy influence and deep citizen engagement in a large-scale citizen science project on ambient air quality in antwerp. *J. Environ. Plan. Manag.* 62, 534–551. doi:10.1080/09640568.2018.1428183

Warin, C., and Delaney, N. (2020). *Citizen science and citizen engagement. Achievements in Horizon 2020 and recommendations on the way forward*. Luxembourg: Publications Office of the European Union.

Watne, Å. K., Linden, J., Willhelmsson, J., Fridén, H., Gustafsson, M., and Castell, N. (2021). Tackling data quality when using low-cost air quality sensors in citizen science projects. *Front. Environ. Sci.* 9, 733634. doi:10.3389/fenvs.2021.733634

Wilkinson, M. D., Dumontier, M., Aalbersberg, Ij. J., Appleton, G., Axton, M., Baak, A., et al. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Sci. Data* 3, 160018. doi:10.1038/sdata.2016.18

Williamson, K., Satre-Meloy, A., Velasco, K., and Green, K. (2018). *Climate change needs behavior change: Making the case for behavioral solutions to reduce global warming*. Arlington, VA: Rare. Available at: https://rare.org/wp-content/uploads/2019/02/2018-CCNBC-Report.pdf.